Chapter#13 ELECTROSTATICS

Electrostatics:-

The branch of physics in which we study about the charges when they are at rest, is called electrostatics.

Electrostatic Induction:-

In the presence of a charged body an insulated conductor develops positive charge at one end and negative charge at the other end. This process is called electrostatic induction.

Electroscope:-

It is an electrical device, which is used to detect the presence of charge on a body. It is also called gold leaf electroscope. It can also be used to detect the nature of charge on a body.

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Q. How can we detect the presence of charge on a body?

Ans: - In order to detect the presence of charge on a body first of all we will bring that body near the disk of an uncharged electroscope. If the body is charged then the leaves of the electroscope will diverge and if that body has no charge on it then leaves of the electroscope will remain at their normal position.

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Q. How can we detect the type of charge on a charged body?

Ans:- In order to detect the type of charge on a body then first of all, the electroscope is charged either with positive or negative charge. Suppose the electroscope is positively charged. Now, in order to detect the type of charge on a body, we bring that body near the disk of positively charged electroscope. If the divergence of the leaves increases then the body carries positive charge on the other hand if the divergence of the leaves decreases than the body has negative charge.

Q. How can we identify conductors and insulators?

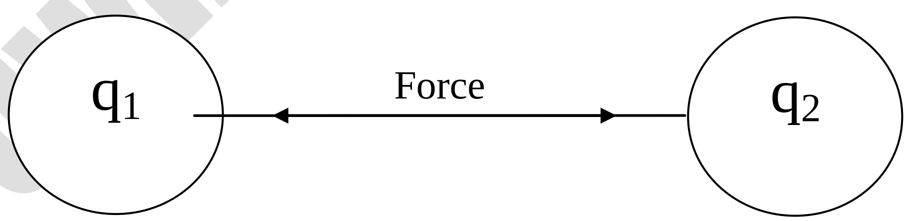
Ans: - Electroscope can be used to distinguish b/w conductors and insulators. For this purpose bring a body under test near the disk of electroscope. If the leaves of electroscope collapse from their diverged position then this body is a conductor. If there is no charge in the divergence of the leaves then it means that the body under test is an insulator.

COULOMB'S LAW

Statement:-

The force of attraction or repulsion between two point charges is directly proportional to the product of the magnitude of charges and inversely proportional to the square of the distance between them.

Explanation:-



Consider two point charges **"q_1"** and **"q_2"** placed at a distance **"r"** from each other. If **"F"** is the force of attraction or repulsion between these charges then according to coulombs law.

$$F \propto q_1 q_2 \longrightarrow (i)$$

$$F \propto \frac{1}{r^2} \longrightarrow (ii)$$

From (i) and (ii)

$$F \propto \frac{q_1 q_2}{r^2}$$

$$F = (\text{constant}) \frac{q_1 q_2}{r^2}$$

Constant = k

So

$$F = \frac{K q_1 q_2}{r^2}$$

Here "K" is the proportionality constant and its value depends upon the medium between two charges. If the medium between two charges is air than value of **"k"** is **"9 x 10^9"** $\frac{N.m^2}{C^2}$

Condition:-

Coulomb's law is true only in case of point charge whose sizes are very small as compared to the distance between them.

Electric Field:-

The space or region around a charge in which it exerts electrostatics force on another charge is called electric field.

Electric Field Intensity:-

The strength of an electric field at any point in space is known as electric field intensity.

Mathematically, it is defined as the **"force acting on a unit positive charge is called electric field intensity".**

Formula:- Electric field intensity = $\frac{Force}{charge}$

$$E = \frac{F}{q}$$

Unit:- Its unit is $\frac{N}{C}$ or NC^{-1}

Quantity:- It is a vector quantity.

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Electric Field Lines OR Electric Lines of Force:-

The direction of electric field intensity in an electric field can be represented by drawing lines. These lines are called electric field lines or electric lines of forces. These lines were introduced Machael Faraday. These lines are imaginary lines and an arrow head indicate their direction.

Properties of Electric Field lines:

- **i.** These lines are always directed from positive charge towards negative charge.
- **ii.** Two electric field lines can never cross each other.
- **iii.** These lines are closer to the points where electric field is strong and they are far apart where electric field is weak.

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Electric potential:-

Electric potential at a point in an electric field is the amount of work done in moving a unit positive charge from infinity to that point.

Formula:- Electric potential = $\frac{Work\ done}{Charge}$

$$v = \frac{W}{q}$$

Unit:- Its unit is volt.

Quantity:- Electric potential is a scalar quantity.

Volt:- We know that $V = \frac{W}{q}$

$$1\text{ volt} = \frac{1\ Joule}{1\ Coulomb}$$

If 1 joule of work is done in moving a charge of 1 coulomb from infinity to a certain point in the field then electric potential will be one volt.

Potential difference:-

The energy supplied by a unit charge as it moves from one point to another point in the direction of electric field is called potential difference between two point.

Explanation:-

Suppose we have two points **"A"** and **"B"**. If the potential of point A is $\mathbf{V_A}$ and the potential of point B is $\mathbf{V_B}$ then potential difference b/w these points is

P.D between **"A"** and **"B"** = $V_A - V_B$.

$= q\,V_A - q\,V_B$

Taking "**q**" **common**

$= q\,(V_A - V_B)$

This potential difference is equal to energy supplied by the charge.

P.D b/w **"A"** and **"B"** = Energy supplied by the charge

So, Energy supplied by the charge = $q\,(V_A - V_B)$

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Capacitor:-

Capacitor is a device which is used to store charge.

Construction:-

A simple capacitor consists of two thin metal plates which are placed parallel to each other having very small distance between them. The medium between the two plates is air or a sheet of some insulator. The medium is known as dielectric.

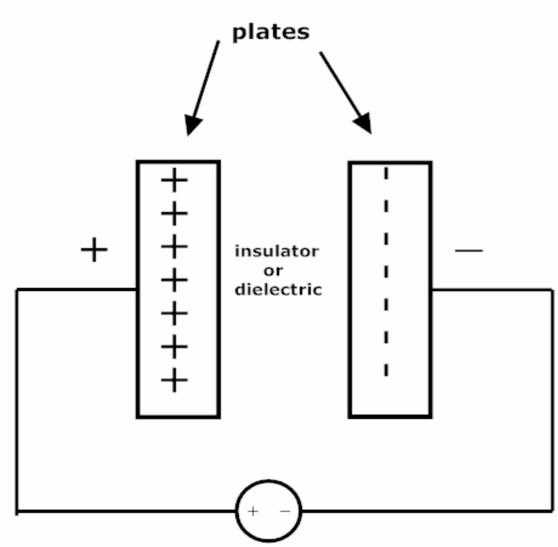


Figure 1: Construction of a capacitor

Working:-

If a capacitor is connected to a battery of **"V"** volt then the battery transfers a charge **"Q"** from plate **B** to plate **A** in such a way that **"– Q"** charge appears on plate **B** and "+

Q" charge appear on plate **"A"**. These opposite charge attract each other and remained bound with in the plates. In this way the charge is stored in a capacitor for a long time.

From different experiments it has been found that the charge **"Q"** stored on the plates of the capacitor is directly proportional to the potential difference across the plates.

$Q \propto V$

$$Q = (\text{constant})\, V$$

$$\text{Constant} = C$$

$$Q = CV$$

So, $$Q = CV$$

Here, **"C"** is constant and known as a capacitance of the capacitor.

Capacitance:-

The ability of a capacitor to store charge is called capacitance.

Unit:- The unit of capacitance is Farad **"F"**.

Farad:- We know that $Q = CV$

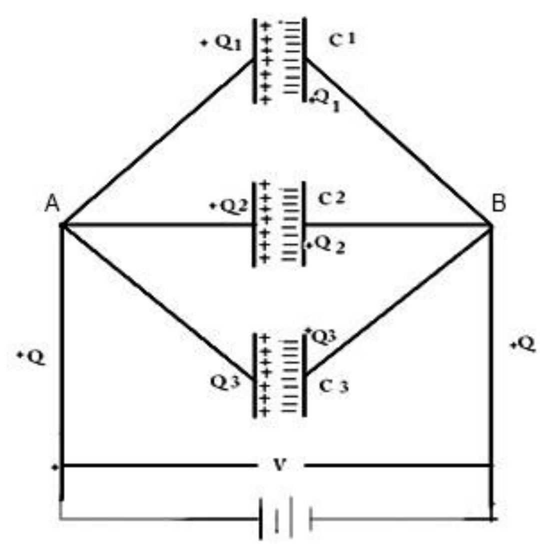
$$C = \frac{Q}{V}$$

$$1 \text{ Farad (F)} = \frac{1\ Coulomb}{1\ Volt}$$

If one coulomb of charge is stored on to the plates of the capacitor having a potential difference of one volt then its capacitance will be one farad.

Parallel Combination of Capacitors:-

Such a combination of capacitors in which left plate of each



capacitor is connected with positive terminal of the battery and right plate of each capacitor is connected with negative terminal of the battery with the help of a wire is called parallel combination of capacitors.

CHARACTERISTICS:-

i) In a parallel combination of capacitors the value of potential difference across each of the capacitor has the same value. $\mathbf{V_1 = V_2 = V_3 = V}$

ii) In parallel combination of capacitor the value of charge across the plates of each capacitor will be different. $\mathbf{Q_1 \neq Q_2 \neq Q_3}$

iii) The total charge supplied by the battery is equal to sum of the charge across various capacitors. Total charge $= Q_1 + Q_2 + Q_3$

$$Q = Q_1 + Q_2 + Q_3$$

Putting values

$$Q = C_1V_1 + C_2V_2 + C_3V_3$$

Here **"V"** is same **i.e** $V_1 + V_2 + V_3 = V$

Taking V common

$$Q = V(C_1 + C_2 + C_3)$$

$$\frac{Q}{V} = C_1 + C_2 + C_3$$

iv) The parallel combination of capacitors can be replaced by a single capacitor. This single capacitor is called equivalent capacitor and its capacitance is called equivalent capacitance. It is represented by **"C_e"**

$$\mathbf{C_e = C_1 + C_2 + C_3}$$

If there are **"n"** number of capacitors connected in parallel then

$$\mathbf{C_e = C_1 + C_2 + C_3 + C_4 + C_5 \ldots\ldots\ldots C_n}$$

v) The equivalent capacitance of parallel combination of capacitor is greater than any of the individual capacitances.

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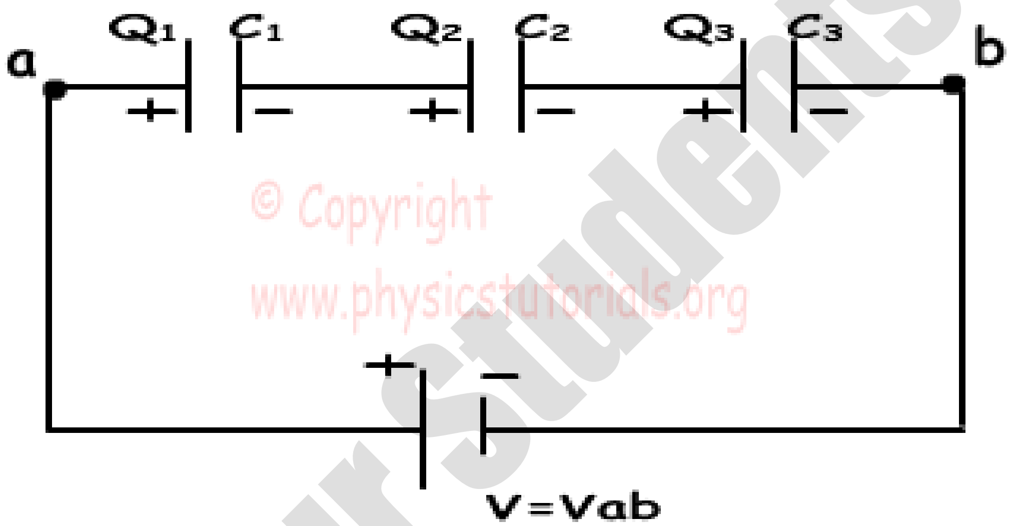
Series Combination of Capacitors:-

Such a combination of capacitors in which all the capacitors are connected side by side in such away that right plate of one capacitor is connected to the left plate of the next capacitor is called series combination of capacitors.



CHARACTERISTICS:-

i. In series combination of capacitors each capacitor has the same amount of charge. If the battery supplies **"+ Q"** charge to the left plate then due to electrostatics induction **"– Q"** charge is induced on the right plate of the capacitor.

$$\mathbf{Q_1 = Q_2 = Q_3 = Q}$$

ii. In series combination of capacitor the value of potential difference across each capacitor is different. $\mathbf{V_1 \neq V_2 \neq V_3}$

iii. The total voltage of the battery is equal to sum of voltages across various capacitors.

$$\text{Total voltage} = V_1 = V_2 = V_3$$

$$V = V_1 = V_2 = V_3$$

Putting values

$$V = \frac{Q1}{C1} + \frac{Q2}{C2} + \frac{Q3}{C3}$$

Here, **"Q"** is same $Q_1 = Q_2 = Q_3 = Q$

So $V = \frac{Q}{C1} + \frac{Q}{C2} + \frac{Q}{C3}$

Taking Q common

$$V = Q\left[\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}\right]$$

$$\frac{V}{Q} = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}$$

iv. The series combination of capacitor can be replaced by a single capacitor. This single capacitor is called equivalent capacitor and its capacitance is called equivalent capacitance. It is represented by **"Ce"**

$$\frac{1}{Ce} = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}$$

If there are **"n"** number of capacitors connected in series then

$$\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4} + \frac{1}{C_5} \text{......} \frac{1}{C_n}$$

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Different Types of Capacitors:-

There are two main types of capacitors.

i. Fixed capacitors.

ii. Variable capacitors.

i. Fixed capacitor:-

Such capacitors in which the plates are immovable and their value does not changes are called fixed capacitors. In fixed capacitors, the plates are static and do not change their position.

Example:- Paper of capacitor and mica capacitors are example fixed capacitors.

☆ **Paper Capacitors**:-

Paper capacitor is an example of fixed capacitors. It is cylindrical in shape. Usually an oiled or greased paper or a thin plastic sheet is used as a dielectric between two aluminum foils. The oiled paper or plastic sheet is rolled in cylindrical shape and then it is enclosed into a plastic case.

☆ **Mica Capacitors**:-

Mica capacitor is an example of fixed capacitors. In these capacitors a thin mica sheet is used as dielectric between two metal plates. This capacitor is enclosed in a plastic case in such a way that the wires attached to the plates are projected outside the plastic case for making connections.

If the capacitance of the capacitor is to be increased then large number of plates are piled up one over the other having layers of dielectric between them.

☆ **Variable Capacitor**:-

Such capacitors in which the plates are moveable and their value can be change are called **"variable capacitor"**. In variable capacitor some arrangement is made to change the area of the plates facing each other. A Variable capacitor is basically a combination of many capacitors with air as dielectric.

Construction:-

A variable capacitor consists of two sets of plates. One set remains static while the other set can rotate in such a way that the distance between the plates does not change and they do not touch each other. The capacitance of the fixed capacitor depends upon the common area of the plates which faces each other. If the plates rotate inward then capacitance increases. If the plate rotates outward then capacitance decreases. Variable capacitors are used for tuning radio sets.

Electrolytic Capacitor:-

An electrolytic capacitor is a special type of capacitor which can store large amount of charge at a very low voltage. It consists of metal foil in contact with an electrolyte. When a voltage is applied between the metal foil and the electrolyte then due to motion of ions a very thin layer of metal oxide is formed on the foil. This thin layer of metal oxide acts as dielectric. Due to this thin layer of dielectric large amount of charge can be stored on the capacitor.

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Uses of Capacitor:-

i. Capacitors are used in table fans, ceiling fans, exhaust fans, air conditioners, cooler, motors, washing machines and many other appliances.
ii. Capacitors are used in electric circuit of computers.
iii. Capacitors are used for tuning transmitters, receivers and transistor radios.
iv. Capacitors are used to separate high frequency and low frequency signals.

v. Capacitors are used in the resonate circuits which are used for tuning radios at particular frequencies.

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Electrostatic Power Pointing: -

In automobile industry static electricity is used to point new model cars. In this process the body of the car is charged with positive or negative charge. After this the point is given opposite charge by charging the nozzle of the sprayer. Due to mutual repulsion the charge particles of the point are attracted by the oppositely charged car. These charged particles are evenly distributed on the body of the car and stick much batter and a very thin layer of the paint is produced on the body of the car.

Chapter # 13 **NUMERICAL PROBLEM**

13.1:- The charge of how many negatively charged particles would be equal to 100 μC. Assume charge on one negative particle is 1.6 x 10^{-19} C?

Given: - charge = q = 100 μC

= 100 x 10^{-6} C

Number of negative charges = n =?

Charge on one negative particle = 1.6 x 10^{-19} C = e

Solution:-

We know that

13.2:- Two point charges q_1= 10 μC and q_2 5 μC are placed at a distance of 150 cm. what will be the coulomb's force between them? Also find the direction of the force.

Given: first charge = q_1= 10 μC

= 10 X 10^{-6} C

Second charge = q_2= 5 μC

= 5 x 10^{-6} C

Distance = r = 150 cm

$= \frac{150}{100} = 1.5$ m

Coulomb's force = f=?

$q = ne$

Where,

e = negative charge

$e = 1.6 \times 10^{-19}C$

Now,

$q = ne$

By putting values

$100 \times 10^{-6} = n\,(1.6 \times 10^{-19})$

$\frac{100 \times 10^{-6}}{1.6 \times 10^{-19}} = n$

$n = \frac{100\,(10^{-6+19})}{1.6}$

$n = \frac{100\,(10^{13})}{1.6}$

$n = 62.5 \times 10^{13}$

$n = 6.25 \times 10^{13+1}$

$n = 6.25 \times 10^{14}$

$n = 6.25 \times 10^{14}$ Ans.

Direction of force =?

Solution:-

According to coulomb's law,

$F = \frac{q_1 q_2}{r^2}$

By putting values,

$F = \frac{(9 \times 10^{9})(10 \times 10^{-6})(5 \times 10^{-6})}{(1.5)^2}$

$F = \frac{(9 \times 10 \times 5) \times 10^{9-6-6}}{2.25}$

$F = \frac{450 \times 10^{-3}}{2.25}$

$F = 0.2$ N Ans.

<u>Direction</u>:

Since both charges "q_1" and "q_2" are positive, so force of repulsion is present between them.

13.3:- The force of repulsion between two identical positive charges is 0.8 N, when the charges are 0.1 m apart. Find the value of each charge.

Given: - force = f = 0.8 N

Distance = r = 0.1 m

1^{st} charge = q_1 = q =?

2^{nd} charge = q_2 = q =?

Solution:-

According to coulomb's law:

$$F = \frac{K\,q_1\,q_2}{r^2}$$

$$F = \frac{K\,q\,q}{r^2}$$

$$F = \frac{K\,q^2}{r^2}$$

By putting values:

$$0.8 = \frac{(9\,x\,10^9)(q^2)}{(0.01)}$$

$$(0.8)\,(0.01) = (9\,x\,10^9)(q^2)$$

$$0.008 = (9\,x 10^9)\,(q^2)$$

$$\frac{0.008}{9\,x\,10^9} = q^2$$

$$\frac{0.008}{9}\,x\,10^{-9} = q^2$$

$$0.00088\,x\,10^{-9} = q^2$$

$$88\,x\,10^{-9-5} = q^2$$

$$88\,x\,10^{-14} = q^2$$

Taking square root on both sides:-

$$\sqrt{88\,x\,10^{-14}} = \sqrt{q^2}$$

$q = 9.38\,x\,10^{-7}$C Ans.

13.4:- Two charges repel each other with a force of 0.1 N when they are 5 cm apart. Find the forces between the same charges when they are 2 cm apart.

Given:-

1^{st} force = F_1 = 0.1 N

1^{st} distance = r_1 = 5 cm

$r_1 = \frac{5}{100} = 0.05$m

2^{nd} force = F_2 =?

2^{nd} distance = r_2 = 2cm

$r_2 = \frac{2}{100} = 0.02$m

Solution:-

As both charges are same

So, $q_1 = q_2 = q$

Now:

By putting coulomb's law,

$$F = \frac{K\,q_1 q_2}{r^2}$$

$$F = \frac{K\,q\,q}{r^2}$$

$$F = \frac{K\,q^2}{r^2}$$

For first force: $F_1 = \frac{K\,q^2}{r_1^2}$ ⟶ (i)

For second force: $F_2 = \frac{K\,q^2}{r_2^2}$ ⟶ (ii)

Dividing equation ——— (ii) by (i)

$$\frac{F_2}{F_1} = \frac{\frac{K\,q^2}{r_2^2}}{\frac{K\,q^2}{r_1^2}}$$

$$\frac{F2}{F1} = \frac{K\,q^2}{r_2^2} \div \frac{K\,q^2}{r_1^2}$$

$$\frac{F2}{F1} = \frac{K\,q^2}{r_2^2} \times \frac{r_1^2}{K\,q^2}$$

By putting values:-

$$\frac{F_2}{0.1} = \frac{(0.05)^2}{(0.02)^2}$$

$$\frac{F_2}{0.1} = \frac{0.0025}{0.004}$$

$$\frac{F_2}{0.1} = 6.25$$

$F_2 = (6.25)\ (0.1)$

$F_2 = 0.625$ N Ans.

13.5:- the electric potential at a point in an electric field is 10^4 V. if a charge of +100 μC is brought from infinity to this point. What would be the amount of work done on it?

Given:-

Electric potential = v = 10^4 volt

Charge = q = 100 μC = 100 x 10^{-6} C

Work done = W.D =?

Solution:-

We know that

$$\text{Electric potential} = \frac{Work\ done}{Charge}$$

$$V = \frac{W}{q}$$

$$10^4 = \frac{W}{(100 \times 10^{-6})}$$

$$(10^4)(100 \times 10^{-6}) = W$$

$$100 \times 10^{-6+4} = W$$

$$100 \times 10^{-2} = W$$

$$\frac{100}{10^{+2}} = W$$

$$\frac{100}{100} = W$$

1 J = W Ans.

13.6:- A point charge of +2 is transferred from a point at potential 100 V to a point at potential 50V. What would be the energy supplied by the charge?

Given:-

Charge = q = 2C

1^{st} potential = V_A = 100 volt

2^{nd} potential = V_B = 50 volt

Energy = E =?

Solution:-

We know that

$$\text{Electric potential} = \frac{Work\ done}{Charge}$$

$$V = \frac{W}{q}$$

Here work = energy

And, $V = V_A - V_B$

So, $V = 100 - 50 = 50$volt

$$V_A - V_B = \frac{Energy}{Charge}$$

$$100 - 50 = \frac{E}{2}$$

$$50 \times 2 = E$$

100 J = E

13.7:- A capacitor holds 0.06 coulombs of charge when fully charged by a 9 volt battery. Calculate capacitance of the capacitor.

Given:-

13.8:- A capacitor holds 0.03 coulombs of charge when fully charged by a 6 volt battery. How much voltage would be required for it to hold 2 coulombs of charge?

Given:-

Charge = q = 0.06C

Voltage = v = 9 volt

Capacitance = C = ?

Solution:-

We know that

$$q = CV$$

$$0.06 = C(9)$$

$$\frac{0.06}{9} = C$$

$$C = 0.00666 \text{ F}$$

$$C = 6.66 \times 10^{-3} \text{ F Ans.}$$

1st charge = q_1 = 0.03C

Given voltage = V_1 = 6volt

2nd charge = q_2 = 2C

Required voltage = V_2 =?

Solution:-

For a same capacitor capacitance

"C_1" = "C_2" = C

We know that

$$Q = CV$$

Also, $q_1 = CV_1$ ⟶ (i)

And, $q_2 = CV_2$ ⟶ (ii)

Dividing equation (i) and (ii)

$$\frac{q_1}{q_2} = \frac{CV_1}{CV_2}$$

$$\frac{q_1}{q_2} = \frac{V_1}{V_2}$$

By putting values

$$\frac{0.03}{2} = \frac{6}{V_2}$$

$$0.015 = \frac{6}{V_2}$$

$$V_2 = \frac{6}{0.015}$$

$$V_2 = 400 \text{ volt Ans.}$$

13.9:- two capacitors of capacitances 6 μF and 12 μF are connected in series with 12V the battery. Find the equivalent capacitance of the combination. Find the charge and the potential difference across each capacitor.

Given:-

1st capacitance = C_1 = 6 μF = 6×10^{-6} F

2nd capacitance = C_2 = 12 μF = 12 x 10^{-6} F

Voltage of battery = V = 12 volt

Equivalent capacitance = Ce =?

Charge of 1st capacitor = q_1 =?

Charge of 2nd capacitor = q_2 =?

P.D of 1st capacitor = V_1=?

P.D of 2nd capacitor = V_2 =?

Solution:-

We know that,
In series combination value of charge

Remains the same i.e.

$$q_1 = q_2 = q$$

And value of equivalent capacitance is given by:

$$\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\frac{1}{C_e} = \frac{1}{6} + \frac{1}{12}$$

$$\frac{1}{C_e} = \frac{2+1}{12}$$

$$\frac{1}{C_e} = \frac{3}{12}$$

$$\frac{1}{C_e} = \frac{1}{4}$$

Ce = 4 μF

Ce = 4 x 10^{-6} F

Now using formula:-

$$Q = CV$$

Here, $q = CeV$

$q = (4 \times 10^{-6})(12)$

$q = 48 \times 10^{-6}$ C

So, $q_1 = q_2 = q = 48 \times 10^{-6}$C

Now,

For V_1 $q_1 = C_1V_1$

$48 \times 10^{-6} = (6 \times 10^{-6})\, V_1$

$$\frac{48 \times 10^{-6}}{6 \times 10^{-6}} = V_1$$

$$\frac{48 \times 10^{-6+6}}{6} = V_1$$

8 volt = V_1

Again, $q = CV$

For V_2 $q_2 = C_2V_2$

$48 \times 10^{-6} = (12 \times 10^{-6})\, V_2$

$$\frac{48 \times 10^{-6}}{12 \times 10^{-6}} = V_2$$

4 volt = V_2 Ans.

Q.1:- An electric field rod attracts pieces of papers. After a while these pieces fly away why?

Ans: An electric field rod attracts pieces of paper because opposite charge is induced on them. When these pieces stick to the rod, they acquire similar charge as on the rod. Therefore, due to repulsion between similar charges the pieces of paper fly away after a while.

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Q. Is the equivalent capacitance of series capacitors larger or smaller than the capacitance of any individual capacitor in the combination?

Ans:- In series combination of capacitors the equivalent capacitance is given by,

$$\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

From this relation we see that the value of equivalent capacitor is less than the value of any individual capacitor.

QUESTION

13.6:- Perhaps you have seen a gasoline truck trailing a metal chain beneath it. What purpose

does the chain serve?

Ans:-A metallic chain can be seen hanging from the back side of a petrol tanker. As the tanker moves then this chain rolls on the road. Due to friction with air the body of the tanker gets charged and a tiny spark can cause huge explosion. But this charge is continuously transferred to the ground through by this metallic chain.